Measurement reporting in a telecommunication system

Field of the invention

This invention concerns reporting of measurements on radio interface in a telecommunication system.

Background of the invention

In mobile telecommunication systems mobile stations MS can use the services provided by the network using radio connections. The radio connection uses the channels of called radio interface between the mobile station and a base station of the mobile telecommunication network. Only a limited bandwidth on the radio spectrum is allocated to be used by the telecommunication systems. To gain capacity enough, the channels must be used again as densely as possible. To achieve this, the coverage area of the system is divided into cells, each cell being served by one base station. Due to this, the mobile telecommunication systems are often also called cellular systems.

The network elements and the internal relation between the network elements of a mobile telecommunication system are presented in Figure 1. The network presented in the figure is in accordance with the UMTS system currently being standardized by ETSI (European Telecommunications Standards Institute). The network comprises base stations BTS (Base Transceiver Station), that can establish connections with the mobile stations MS, Radio Network Controllers RNC controlling the usage of base stations and Mobile Switching Centers MSC controlling the RNC's. In addition, the network comprises a Network Management System NMS, with the help of which the operator can modify the parameters of the other network elements. The interface between the MSC and the RNC's is generally called the Iu interface. The interface between the RNC's and the BTS's is the Iubis interface and the interface between the BTS and the MS's the radio interface. According to some proposals, an interface Iur between the RNC's is specified.

The calls of a mobile station are routed from the BTS via the RNC to the MSC. MSC switches the calls to other mobile switching centers or to

the fixed network. The calls can as well be routed to another mobile station under the same MSC, or possibly even under the same BTS.

The radio interface between the base stations and the mobile stations may be divided into channels using a plurality of divisions. Known methods of division are, for example, Time Division Multiplexing TDM, Frequency Division Multiplexing FDM and Code Division Multiplex CDM. In TDM systems, the spectrum allocated for the system is divided into successive time frames consisting of time slots, each time slot defining one channel. In FDM the channel is defined by the frequency used in the connection. In CDM the channel is defined by the spreading code used in the connection. These methods can be used separately or be combined.

To be able to successfully communicate with the mobile telecommunications network, the mobile station continuously monitors the radio signals sent by the base stations. In the idle mode the mobiles decode the strongest signal received, and when needed request the establishment of a connection from the base station transmitting this signal.

During an active connection, the connection can be moved from one base station to another. The connection can be moved from one base station to another by simply rerouting the signal, which is called hard handover. The system interference can be decreased and thus the capacity increased especially in CDMA (Code Division Multiple Access) systems utilizing CDM by using soft handovers in which the mobile has simultaneously connections with a plurality of base stations, these base stations forming the so called active set of the connection.

The handover may be

- intra-cell handovers
- inter-cell handovers between two base stations under the same radio network controller
- inter-RNC handovers between two RNC's under the same MSC, or
- inter MSC handover between two cells under different MSC's.

In addition, the handover can be divided into intra-frequency handovers in which all the channels involved in the handover procedure are on the same frequency and inter-frequency handovers, in which there are channels from at least two frequencies involved in the handover procedure.

To be able to establish the handovers to right base stations during an active connection, the mobile station continuously measures the radio

signals from the base stations it is in connection with as well as their neighboring base stations. The measurement results are transmitted to the network using the measurement reporting scheme specified in the system. Based on the reports, the network initiates the handover when the mobile station would have a better or at least sufficiently good radio connection to another base station.

In addition to the network initiated handovers, also mobile evaluated handovers are known. In an exemplary description of a mobile evaluated handover, the mobile station monitors the signal levels received from neighboring base stations and reports to the network those beacon signals which are above or below a given set of thresholds. Those thresholds can be dynamically adjusted as will be explained in the following. Based on this reporting scheme, the network will decide whether the active set of the connection is to be changed.

Two type of thresholds are used: the first one to report beacons with sufficient power to be used for coherent demodulation, and the second one to report beacons whose power has declined to a level where it is not beneficial to be used for receiving the sent information. Based on this information, the network orders the MS to add or remove base station signals from its active set.

While soft handover improves overall performance it may in some situations negatively impact system capacity and network resources. This is due to the unnecessary branches between the MS and the base stations in the active set. On the downlink direction from the base stations to the mobile station, excessive branch reduces system capacity while on the uplink direction from the mobile station to the base stations, it costs more network resources.

To solve this problem, the principle of dynamic thresholds for active set management is known in prior art. In this method, the MS detects beacons crossing a given static threshold T1. When crossing this threshold the beacon is moved to a candidate set. It is then searched more frequently and tested against a second dynamic threshold T2. This second threshold T2 will test if the beacon is worth adding to the active set.

When the beacons corresponding to the branches in the active set are weak, adding an additional branch signal, even a poor one, will improve performance. In these situations, a relatively low value of T2 is used. When there is one or more dominant beacons, adding an additional weaker branch

whose beacon signal is above T1 will not improve performance but will utilize more network resources. In these situations a higher value of T2 is used.

After detecting a base station signal above T2, the MS will report it back to the network. The network will then set up the handover resources and order the MS to coherently demodulate the signal of this additional branch.

Beacons can be dropped from the active set according to the same principles. When the beacon strength decreases below a dynamic threshold T3, the handover connection is removed, and the beacon is moved back to the candidate set. The threshold T3 is a function of the total energy of beacons in the active set. When beacons in the active set are weak, removal a branch, even a weak one, will decrease performance. In these situations, a relatively low value of T3 is used. When there is one or more dominant branches, removal of a weaker signal will not decrease performance but will make the utilization of the network resources more efficient. In these situations a higher value of T3 is used. Branches not contributing sufficiently to the total received energy will be dropped. When further decreasing below a static threshold T4 a beacon is removed from the candidate set.

To be able to control the connection, the network needs in different situations different kinds and different amount of measurement information. The more information is sent the more efficient the handover algorithm are. However, the more information the mobile station sends the network, the more radio resources are spent. Thus, the measurement reporting schemes according to prior art are always compromises between the efficiency of the handover algorithms and the usage of radio resources.

WO9802010 relates to a process and a device in a radio communication system for observing the quality of channels that are to be used in uplink and channels that are to be used in downlink. A quality parameter, for example the interference, is measured for both uplink channels and downlink channels from a measurement receiver comprised in each base station. The measured interference is an approximation to the real downlink interference. The approximation has best correspondence with the real interference situation when the base station and the mobile stations are placed at similar height, for instance in micro- and pico cells. The measurement values can be used for adaptive allocation of frequencies or

AMENDED SHEET

channels, or for giving statistical information about the radio communication system.

As the usage of mobile telecommunication systems and multimedia applications requiring large bandwidths is growing, the present methods are no longer sufficient, thus limiting the performance of the mobile telecommunication networks. The objective of the present invention is a flexible measurement reporting scheme which solves this problem.

Summary of the invention

The basic idea of this invention is to define triggers, e.g. threshold values for radio signal parameters, for sending a measurement report separately for downlink and uplink directions. In addition, it is specified how

the outputs of these triggers are to be combined. For example, it may be determined whether the measurement report is to be sent, for example, when both the uplink and downlink conditions are met, when either of them is met, based entirely on the uplink conditions or based entirely on the downlink conditions.

The measurement report types is preferably a mobile evaluated handover measurement report triggering a handover. Such a report is triggered in the mobile station when at least one upper threshold of the radio signal parameters for a mobile evaluated handover is exceeded or lower threshold gone under.

Brief description of the figures

The invention is described more closely with reference to the accompanying schematic drawings, in which

Figure 1 shows a mobile telecommunication system;
Figure 2 shows the structure of a MEHO algorithm;
Figures 3, 4, 5, 6 and 7
each show a decision flow chart, and
Figure 8 shows functional entities in a mobile station.

Detailed description of the invention

In the following, preferred embodiments of the invention are studies further.

In this context mobile evaluated handover means, that a handover measurement algorithm situated in the mobile triggers the handover report. The actual HO decision is always performed by the network. The handover report types can be further divided into intra-frequency and inter-frequency handover report types.

The intra-frequency handover

The algorithm presented in the following includes the possibility to use information about the downlink (DL), uplink (UL) or both as the trigger for the HO report. Also this scheme provides a flexible means to control the information content of the HO report. The actual thresholds and timers in the algorithm are selected to be such, that a wide variety of HO algorithms can be constructed by the appropriate setting of these

The mobile station continuously performs measurements on the radio signals from different BTS's according to the procedure described in the following.

The mobile determines the received power of the beacon channel for BTSi. This power is denoted as Prx,i (mW). The MS performs this measurement for time period t (a parameter set by network). The value of $P_{rx,i}$ is averaged over the measurement period. The result of this operation is denoted as $P\_ave_{rx,i}$. When the measurement is completed, the path loss estimate, denoted as Li (dB), is calculated as:

$$L_i = -10\log_{10}\left(\frac{P\_ave_{rx,i}}{P\_beacon_{tx,i}}\right). \tag{1}$$

In (1), the unit of $P\_beacon_{tx,i}$ is mW.

During the same measurement period t the MS also estimates the interference power of the beacon channel before or after (this is preferably a parameter defined by the network) correlating the received sum signal with the spreading code. The values calculated before or after the correlation differ due to the fact that the correlation remarkably reduces the interference caused by other connections. This interference is denoted as I_i (mW). The interference is also averaged over the measurement period. After the averaging has been performed, the average value is converted into dBm. This average is denoted as I_ave_i.

Sub A1

The MS is also to receive, e.g. on the beacon channel, the DL_offset value of BTS_i, denoted as DL_offset_i (dB), which is a relatively stable parameter and there is thus no need to re-receive it for each measurement period. The purpose of this base station specific parameter is to specify fro different cell sizes. The mobiles are handed over from a first set of cells more willingly than from a second set of cells. These cells of the first set thus become smaller than the cells of the other set. The offset value can be seen as an additional base station specific part of the threshold values that are soon to be presented more closely.

From the above information the MS is to calculate one DL HO measurement $S_{dl,i}$ sample as

$$S_{dl,i} = L_i + I_{ave,i} + DL\_offset_i \tag{2}$$

Sub A8

$S_{dl,i}$ is thus a measure for the carrier to interference ratio CIR of the measured signal. It is to be noted that the larger the value of $S_{dl,i}$, the worse the link from the base station to the mobile station is: The scope of this invention is not limited to the use of this particular measure, but other measures of the link quality may as well be used when implementing the present invention. As one example, the bit error ratio BER in the received radio signal can be used as the measure.

The MS is also to receive, e.g. on the beacon channel, the total interference power , $I_{ul,i}$ (dBm) at the BTS_i and the UL offset value, UL_offset_i (dB) of BTS_i. The MS is then to calculate the value of one UL HO measurement sample as

$$S_{ul,i} = L_i + I_{ul,i} + UL\_offset_i \tag{3}$$

When these measurements and calculations have been performed for BTS_i the MS is then to place the results as the first elements in the vectors L_vect_i (for the value of L_i), $S\_vect_{dl,i}$ (for the value of $S_{dl,i}$) and $S\_vect_{ul,i}$ (for the value of $S_{ul,i}$). The last element of these vectors is discarded. The vectors comprise the history of the measurement results. The length of the history maintained, defined by the length n of these vectors is a network parameter.

Having performed the measurements for this base station signal the MS checks whether a MEHO (Mobile Evaluated HandOver) report is to be transmitted according to the HO algorithm described in the following. The argument of the algorithm may be for instance either median or mean of the vectors $S\_vect_{dl,i}$ and $S\_vect_{ul,i}$, and is preferable defined by the network. In addition, the MS starts to measure the beacon signal transmitted by the next BTS BTS_{i+1}.

The HO algorithm is used to trigger the transmission of the MEHO measurement report. In the algorithm the UL and DL directions of transmission are treated separately. So actually two algorithms can function in the MS independently. The network can command the MS to use either one of them or both for the triggering of measurement report transmission. It should be noted, however, that the active set is always the same for both directions of transfer.

The algorithm includes the below thresholds:

1. Branch addition threshold denoted in this document as BA_abs_{th} and BA_rel_{th} ,
2. Branch deletion threshold denoted in this document as BD_abs_{th} and BD_rel_{th}, and
3. Branch replacement threshold denoted in this document as BR_rel_{th}

For the thresholds 1 and 2, both an absolute and a relative threshold are defined. Separate values can be defined for the uplink and the downlink directions. The thresholds are used in Branch Addition (BA), the Branch Deletion (BD) and the Branch Replacement (BR) decision units. These units may be implemented as hardware units, software blocks or a combination of these.

The basic structure of these algorithms is presented in Figure 2. The uplink comparison unit ULU compares the measurement results of the uplink radio signals to triggers defined by the thresholds set to these signals, and outputs a logical truth value. The downlink comparison unit DLU compares the measurement results of the downlink radio signals to triggers defined by the thresholds set to these signals, and outputs a logical truth value. The results of ULU and DLU are combined to one logical signal using a logical function. The logical value may be, for example, AND or OR function, or a function outputting directly one of the input values of the block. The truth value of this signal is verified, and a report is sent if the truth value is TRUE, for example. Of course, using a different logical function when combining the outputs of ULU and DLU, it can be defined that the report is sent if the truth value is FALSE.

The parallel decision units BA, BD and BR shown in Figure 2 are used in different situations. BA is used when the base station is not in the active set of the connection, and the number of links between the MS and BTS's in the active set is less than a given limit $N_{AS,max}$. The value of $N_{AS,max}$ is a preferably a parameter set by the network.

BD is used when the base station is in the active set of the connection. To prevent ping-pong effect, the logical functions of the BA and BD blocks must be consistent so that the same measurement values for a link between the MS and a BTS may not cause both the units to trigger a measurement report suggesting an addition or deletion of the same link. For example, if logical functions AND and OR are used, the value OR may not be used in both the decision blocks.

BR is used when the base station is not in the active set of the connection and the number of links between the MS and BTS's in the active set is equal to the limit $N_{AS,max}$. This decision unit is used to replace on link of the active set by another one having better radio characteristics.

One algorithmic implementation of the downlink comparison unit DLU of the branch addition algorithm BA is shown in Figure 3. The algorithm is used for beacon signals from base stations that do not belong to the active set. At stage A1 it is checked whether the number of base stations in the active set is less than a predefined limit, i.e. whether the active set is full. As an example, the limit 3 can be used here. If the active set is full, the branch replacement algorithm is selected instead of this algorithm (stage A10).

If the active set is not full the procedure proceeds to stage A2, A3 and A4, in which

- it is checked whether new measurement results have been received (stage A2),
- $S_{i,DL}$ is compared to absolute threshold $BA\_abs_{th,\ DL}$, and
- $S_{i,DL}$ is compared to threshold $S\_best_{i,DL}$+$BA\_rel_{th,DL}$, in which $S\_best_{i,DL}$ id the value measured for the best active branch.

If new results have been received and both the threshold values $BA\_abs_{th,DL}$ and $S\_best_{i,DL}$+$BA\_rel_{th,DL}$ are higher than $S_{i,DL}$, the output of the DLU is set to TRUE.

The uplink branch can be implemented using a similar algorithm. If new results for the uplink have been received and both the threshold values $BA\_abs_{th,UL}$ and $S\_best_{i,UL}$+$BA\_rel_{th,UL}$ are higher than $S_{i,UL}$, the output of the ULU is set to TRUE. The threshold values $BA\_abs_{th,DL}$/ $BA\_abs_{th,UL}$ and $BA\_rel_{th,DL}$/ $BA\_rel_{th,UL}$ used in different directions may be different from each other or identical.

The values of the DLU and ULU algorithms are inputted into the logical function, as shown in Figure 2. MEHO measurement report is sent if the function outputs a value TRUE. For example, if the logical value used is AND, the MEHO measurement report is sent when both the ULU and DLU have value TRUE.

An algorithmic implementation of the downlink comparison unit DLU of the branch deletion algorithm BD is shown in Figure 4. This algorithm is used for beacon signals from base stations that belong to the active set.

It is first checked whether new measurement results have been received (stage D2). The measurement result $S_{i,DL}$ is compared to thresholds

$BD\_abs_{th,UL}$ (stage D3) and $S\_best_{i,DL}+BD\_rel_{th,UL}$ (stage D4). If either of these thresholds is lower than $S_{i,DL}$, the DLU is set to TRUE (stage D5). Otherwise, DLU is set to FALSE (stage D10) and the next beacon signal in the active set is measured.

A similar comparison in made between the uplink measurement results and uplink thresholds to define the value of ULU. DLU and ULU are combined using a logical function defined by the network to make a decision whether to send or not to send a MEHO measurement report. To prevent the ping-pong effect, the logical function used is selected so that the same measurement results never cause the BA to request the addition of a branch and the BD to delete the same branch. To meet this requirement, only one of the logical functions used in BA and BD algorithms according to the same reporting option may be a logical OR function. This is depicted in the following table for two different options for measurement reporting:

	Logical function for BA	Logical function for BD
Option 1	AND	OR
Option 2	OR	AND
Option 3	AND	AND

An algorithmic implementation of the downlink comparison unit DLU of the branch replacement algorithm BR is shown in Figure 5. The algorithm is used for beacon signals from base stations that do not belong to the active set. At stage R1 it is checked whether the number of base stations in the active set is equal a predefined limit, i.e. whether the active set is full. As an example, the limit 3 can be used here. If the active set is not full, the branch addition algorithm is selected instead of this algorithm (stage R10).

If the active set is full the procedure proceeds to stage in which it is checked whether new measurement results have been received (stage R2). If no new measurement results have been received, the next beacon signal is studied. If new measurement result $S_{i,DL}$ has been received it is compared at stage R3 to the measurement value $S\_worst_{i,DL}$ of the worst link in the active set. If $S\_worst_{i,DL}$ exceeds $S_{i,DL}$ with a margin of BR_rel_{th} DLU is set to TRUE (stage R4). Otherwise ULU is set to FALSE (stage R20) and the measurements on a next BTS not belonging to the active set studied.

The uplink branch can be implemented using a similar algorithm. In this comparison, $S_{i,UL}$ is compared to $S\_worst_{i,DL}$ of the worst link in the active set. If $S_{i,DL}$ exceeds $S\_worst_{i,DL}$ with a margin of BR_rel_{th} DLU is set to TRUE. The margin values BR_rel_{th} are preferably identical in downlink and uplink directions, but also different values in different directions can be used. This is a parameter that is defined by the network. DLU and ULU are combined using a logical function to make a decision whether to send or not to send an MEHO measurement report. The logical function is preferably an logical AND function. In another preferred embodiment, the logical function can be adjusted freely by the network. The output of the logical function can be, e.g. the truth value of DLU or ULU.

When the MEHO algorithms in the mobile station trigger the measurement report the status of the M best cells/sectors is transmitted. The transmitted measurement report is always to include the appropriate values for the active set. The M best cells/sectors are determined by using the values of $S_{i,dl}$ or $S_{i,ul}$ depending on whether it was DL or UL algorithm that triggered the report. The contents of the report is preferably determined with an message sent from the network. The measurement report includes, e.g. the following values for each cell/sector to be reported. These values are the filtered values.

1. $S_{i,dl}$
2. $S_{i,ul}$
3. L_i

It should be noted, that the measurement report can include information only about neighbour BTSs whose beacon signals have been decoded. Thus the handover report has to include the information of the number of BTSs that are being reported.

Also the information included in the measurement report may preferably be defined by the network. For example, the number of beacon signals whose power level is to be reported in a measurement report is preferably defined by the network.

The Inter-frequency HO

The inter-frequency measurements are always initiated by the network. Thus the mobile can perform inter-frequency MEHO only after the

network has first commanded the MS to start the inter-frequency HO measurements.

There are at least three different reasons for inter-frequency HO:

1. Coverage. The MS is e.g. exiting the coverage area of a microcell and has to hand over to a macrocell. This case may be relatively simple. For example if the branch deletion has triggered a measurement report and only one branch is active the conclusion by the network is, that the MS is exiting the coverage area. The network responds to this by transmitting a message 'start i-f measurements'. This message includes the possible candidate BTSs. The mobile would then start searching for a stronger BTS on the other frequency. The transmission of the measurement report is triggered when the MS finds a candidate BTS on the other (new) frequency that is stronger than the best active branch on the current frequency.
2. Load. If for some reason the load on the used frequency is higher than on some other available frequency an inter-frequency HO may be appropriate. This situation would probably be known only by the network. After the network has detected the overload situation the actions are the same as in case 1
3. Mobile speed. The speed of the MS is so high, that an excessive amount of handovers are needed if the MS is connected to the microcell layer. This is an item for further study. The most crucial question is the detection of the MS speed. That is, there a method to reliably estimate the MS speed? Can the received beacon powers be measured often enough to be able to use fast fading based methods? What signalling does the MS use to indicate its' speed if the estimation is in the mobile?

After the MS has been commanded by the network to start the inter-frequency measurements the MS is to perform the measurements on the frequency given in the start measurement command.

The algorithm is used to trigger the transmission of the inter-frequency measurement report. In the algorithm the UL and DL directions of transmission are treated separately. So, actually two decision algorithms, DLU and ULU function in the MS independently. The outputs of these

algorithms are combined as shown in Figure 2 to make the final decision conceming sending the measurement report. The network can command the MS to use either one of them or both for the triggering of measurement report transmission. It should however be noted, that the active set is always the same for both directions of transfer.

The algorithm includes the below threshold. For the threshold an absolute and a relative threshold CF_abs_{th} and CF_rel_{th} are defined. The decision flow chart for DLU unit of the algorithm is shown in Figure 7.

If new measurement results have been acquired in the new frequency not belonging to the active set, the link losses the beacon signal is suffering are compared to an absolute threshold CF_abs_{th}. If the quality of the link is sufficient it is compared to the best link in the active set. If the quality is better with a predetermined margin the output of the DLU algorithm is set to TRUE.

A similar algorithm ULU is run for downlink direction. The outputs of DLU and ULU are combined using a logical function as described earlier.

When the HO algorithms trigger the inter-frequency measurement report the status of the M best cells/sectors is transmitted. The M best cells/sectors are determined by using the values of $S_{i,dl}$ or $S_{i,ul}$ depending on whether it was DL or UL algorithm that triggered the report. The contents of the report is determined with a message sent from the network. The measurement report includes, e.g. the following values for each cell/sector to be reported. These values are the filtered values.

1. $S_{i,dl}$
2. $S_{i,ul}$
3. L_i

It must be noted that the possible logical functions are not limited to those presented in the examples above. For instance, if the outputs of the DLU and ULU functions are not binary but have more levels or are even continuous functions triggered by some events on the radio signals in respective directions, fuzzy logical functions can be used when making the decision whether to send or not to send a measurement report based on the outputs of the functions DLU and ULU. The fuzzy logical functions are preferably given by the network.

A mobile station according the invention is shown in Figure 8. As its characteristics, the mobile station has

- receiving means for receiving information about first and second set of trigger conditions corresponding, respectively, to uplink and downlink signals and a logical function,
- monitoring means for monitoring the radio signals,
- checking means which is responsive to the receiving means and the monitoring means and which has the functionality of checking the state of each trigger conditions,
- combining means responsive to the checking means for combining the states according to the logical function, and
- sending means responsive to the combining means for sending a measurement report to the base station.

According to a preferred embodiment,

- the receiving means are arranged to receive a first combination of a first and a second set of trigger conditions and the logical function and a second combination of a first and a second set of trigger conditions and the logical function, and
- the checking means and the combining means are arranged to use the first combination for radio signals from or to active base stations having an active link with the mobile station and the second combination is used for radio signals from or to candidate base stations not having an active link with the mobile station.

The measurement reporting scheme according the invention provides flexible means for reporting measurement results. The advantage of the flexibility is that the measurement reporting can be adjusted to provide the network the necessary information while minimizing the amount of radio resources spent for the measurement reporting purposes.

The invention has been described above by means of preferred embodiments to illustrate the principles of the invention. As regards the details, the invention may vary within the scope of the attached claims.